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DESIGN OF THE ATLAS 240 KV MARX MODULES

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Abstract

A prototype 240 kV, oil-insulated Marx module has been designed and constructed at the Los Alamos National Laboratory (LANL). The prototype will be used for testing and certifying the design of the Marx module and certain components, including the closing switches, series resistor, and the capacitors themselves. The prototype will also be used to evaluate proposed mechanical systems designs. Information gained from the construction and testing of the 4-capacitor prototype will be folded into the design of the 16-capacitor maintenance unit.

The prototype module consists of four 60 kV capacitors, two closing switches, one shunt resistor, and one series resistor. Cables are used to deliver the current to a dummy load scaled to match Atlas system parameters. The Marx unit is contained in a structure made from G-10, suspended from a steel frame that also serves to support components of the trigger, charging, and control system. Appropriate safety and charging systems are an integral part of the prototype design.

The Atlas Marx Module

Atlas is a facility being designed and built at Los Alamos National Laboratory (LANL) to perform high energy-density experiments for weapon-physics and basic research programs¹. The Atlas capacitor bank will store 36 MJ of energy in a ring of 152 oil-insulated Marx modules, each module containing four 60-kV capacitors, two "railgap" switches, one shunt resistor, one stainless steel series resistor, and a array of 240 kV coaxial output cables. Four Marx modules plus a trigger system, charging system, data acquisition and controls system comprise one Maintenance Unit (MU). Figure 1 shows a schematic view of a Marx unit, and figure 2 shows an assembly view of an MU.

The Atlas Marx module will have an erected voltage of 240 kV and a stored energy of 240 kJ. The series resistance will be 270 m Ω and the shunt resistance will be 5.2 Ω . Each Marx module will be capable of delivering a peak current of approximately 330 kA in 4.5 μ sec. The capacitors are double-ended FASTCAP-style units with ratings of 33.5 μ F, 60 kJ, 15 nH, and 20% reversal². The rail-gap switches are capable of carrying a nominal current of 420 kA and a fault current of 720 kA with 5 C nominal coulomb transfer³. The gaps will switch 120 kV and will be insulated with a mixture of 88% Argon and SF₆.

Marx Prototype Design

The Marx module as shown in Fig. 1 is the "building block" from which the machine will be constructed. In order to test the mechanical and electrical design basis for the Maintenance Units, it was decided to build a smaller version of the MU comprised of

Figure 1: Atlas Marx Module

Figure 2: Atlas Maintenance Unit
(one unit not shown for clarity)

the basic single Marx building block. This is called the "4-cap prototype", and is shown in Figure 3.

Figure 3: 4-capacitor Marx prototype

As in the full-size MU, sheets of 3/4 inch thick G-10 are used as vertical support members for the capacitor bundles. The capacitor pairs rest on blocks of Delrin that are bolted to the G-10 plates. The vertical support plates are bolted, in turn, to the pieces of structural steel that make up the strongback. The strongback rests on the support frame and transfers the load of the prototype to the frame instead of the oil tank. In the Atlas machine the walls of the oil tank will support the weight of the Marx units, but the oil tank we are using for the prototype was not designed such that it's walls will support a vertical load.

The series resistor attaches across the inner pair of capacitors (see Fig. 1 also), and the output cable assembly attaches across the top and bottom capacitors. Fourteen RG-220 cables (not shown in Figure 3) go from the output cable assembly to the top of the dummy load.

The series resistor consists of a 54 foot long sheet of 4 mil thick stainless steel sandwiched between two sheets of kapton that are each 2 mil thick. This 54 foot long steel-kapton strip is then accordion folded longitudinally every half inch until the entire strip is two feet long. The accordion fold is sandwiched between two terminals which as connections to the capacitors. Each module has a series resistance of 270 m Ω .

The Shunt damping resistor consists of tygon tubing filled with Copper Sulfate solution. Each module has a shunt resistance of $5\ \Omega$.

Modularity and the Prototype Design

The Atlas machine must be capable of doing 100 shots per year, or two shots per week⁴. This shot rate dictates that there be a high degree of modularity designed into the Atlas system, such that downtime incurred when replacing components, whether for reasons of damage or routine maintenance, is minimized.

The modular approach to the design is most apparent in the concept of the MU. As shown in Fig. 2, each MU is a "self contained" array of Marx units, containing its own diagnostics and data acquisition systems, trigger systems, gas supply manifolds, and shorting system. The design is such that each MU can be assembled, and its operability verified, before it is connected to the transmission lines. Each MU should be perfectly interchangeable with any other MU.

During the operation of the machine, it will be necessary to remove an MU at a given interval⁵ such that routine maintenance can be performed on its rail gap switches. Removal of the MU can be accomplished by disconnecting a shorting switch and breaking a few other connections such as gas and power. The MU can then be removed from the oil tank. Another MU, which has already been assembled and qualified, will be inserted in its place, and the MU that has been removed from the tank will be readied for cleaning. It is only through the design of a modular MU that this sort of rapid change-out can be achieved.

Similarly, it is reasonable to assume that items within the MU may need to be replaced now and again. The desire for modularity, in addition to ease of handling, also played a role in the design of the capacitor bundle, as shown in Figure 4.

Figure 4: Exploded Assembly View of Capacitor Pair

- The assembly sequence of a capacitor bundle will occur as follows:
1. The bottom capacitor is placed on a working surface.

2. A sheet of HDPE and two sheets of polyester matting are placed on top of the capacitor. These sheets provide for proper "hold off" distance to prevent flashing through the case, and also aid in wicking oil between the capacitors.
3. The second capacitor is placed on top of the first.
4. Two 90 degree angles made of Extren are placed between the support rails which are glued on to the capacitor body.
5. A DELRIN "glider pad" is affixed to the angles, which are bolted together.
6. The polyester banding is then applied and shrunk, compressing the support rails against the tee shape formed by the Extren angles. The Extren tees then serve as a means of handling the capacitor bundle, usually by placing forklift tines under the tee.
7. The rail-gaps are bolted to the capacitors with an interface rail bushing. Multi-lam brand fingerstock is used to insure good electrical contact between the interface rail and the capacitor bushing.

Recall from Fig. 3 the DELRIN blocks bolted to the vertical G-10 sheets: the blocks and G-10 form a sort of "shelf". The Extren angles in the cap bundles rest on these shelves, and with the addition of the DELRIN "glider pad" to the Extren angles, it is fairly easy to lift the cap bundle with a forklift and slide the bundle off of the tine into the G-10 shelf structure. Bolts serve to secure the Extren angles to the DELRIN blocks once the bundles are in place, and prevent the bundles from sliding out when the prototype is moved.

After loading in two capacitor bundles, the series resistor and output cable assembly are bolted on, and other components are assembled as required.

Constructed Prototype

As of July 1997 the prototype has been completely constructed, with the exception of the final series resistor. Instead, a metal plate will be utilized which will allow us to fire the Marxes at a lower voltage level and allow us to begin testing the units. Upon successful fabrication of a series resistor, the prototype will be operated at full voltage as a proof of design.

¹ W.M. Parsons, et al, "The Atlas Project-A New Pulsed Power Facility for High Energy Density Physics Experiments", IEEE Transactions on Plasma Science: Special Pulsed Power Edition, Vol. 25, No. 2, April, 1997.

² Reass, et. al, "Capacitor and Rail-Gap Development for the Atlas Machine Marx Module", Proc. 10th IEEE International Pulsed Power Conference, 1995.

³ IBID

⁴ Parsons, et. al.

⁵ Lopez, E.A., et. al, "Rail-Gap Switch Modifications and Test Data for the Atlas Capacitor Bank", Proc. 11th IEEE International Pulsed Power Conference, 1997.

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